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Lifetime Measurements on Carbon Stripper Foils

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One of the most exciting recent developments in accelerator technology is the new breed of electrostatic accelerators. These machines have terminal potentials of 25 million volts and higher and are being built to accelerate intense beams of heavy ions. One such accelerator is now nearing completion at ORNL. A crucial component in these--as in any electrostatic accelerator--is a tiny bit of carbon in the form of a very thin foil. These foils, called stripper foils, are used to strip electrons from atoms so that they will be accelerated to high energy by the electrostatic potential. While carbon foils are not the only method of stripping electrons, they have a number of advantages over the alternative gas strippers. In particular, they produce higher charge states which are essential for providing the energetic ions required for heavy ion physics experiments. Because of the importance of stripper foils to the most efficient operation of the new ORNL accelerator, we are quite interested in their properties and in improving their performance.

Carbon foils have been in use for many years in smaller accelerators. One property of these foils that has been well established is that their performance detericrates under bombardment by energetic ions. One of the reasons for the deterioration is that the foils shrink parallel to the foil in the irradiated area. This causes an effective thickening of the foil resulting in increased multiple scattering and loss in extracted beam intensity. The shrinkage also results in stresses in the surrounding unirradiated foil which can lead to mechanical failure of the foil.

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Since the rate of shrinkage increases for heavier projectiles and higher beam currents, stripper foil failure can represent an important limitation on the efficient operation of the new and costly accelerators.

Until recently, stripper foils had traditionally been made by vapor deposition techniques. In this method, the carbon is vaporized by a carbon arc or electron gun heating and collected on coated glass substrates which are normally near room temperature. Recently, Takeuchi and coworkers in Japan reported dramatic improvements in vapor deposited foils by using carefully prepared heated substrates. Similar improvements have also been reported recently by researchers at Daresbury in the U.K. using a quite different technique. In the Daresbury experiments, foils were produced by cracking hydrocarbon gases in a glow discharge with carbon being deposited on the substrate which served also as the cathode. While this technique had been used earlier to produce adherent films, this was the first successful production and testing of self-supporting foils. These successes led to the current ORNL efforts on carbon foil production and testing.

Initial screening experiments were begun in March, using foils supplied by J. L. Gallant from Chalk River Laboratories in Canada. Gallant had successfully produced and tested foils using both the hot substrate and glow discharge techniques and kindly provided specimens to be tested on the ORNL EN tandem accelerator facility. These tests were performed in March using a 10 MeV chlorine beam. In these preliminary tests, we found that both types of foils had lifetimes which were an order of magnitude or more longer than our conventional foils. Since both types appeared to have comparable lifetimes, the decision was made

to develop a production facility at ORNL based on the glow discharge technique. The choice of technique was based on its inherent simplicity and the likelihood of highly reproducible results.

The glow discharge chamber used at ORNL consists of a modified desiccator jar and is shown in Slide 1. Here one can see the inlet port for the gas mixture, the vacuum pumping port, and the electrodes. It was found that a separate anode was not required and thus the aluminum top serves as both the anode and the vacuum seal. The cathode, on which the substrate is placed during the glow discharge, is a copper plate supported by a teflon insulator. The cathode is connected to the negative high voltage supply through a 5000-ohm ballast resistor which suppressed arc discharges. Since the volume of the chamber is quite small, a continuous flow of gas is maintained during the discharge. Following evacuation of the system with a diffusion pump, a mechanical pump is opened to the system and the gas flow adjusted to give a pressure of 100 microns in the chamber, the pressure being that on a capacitance gauge connected to the vacuum line. The glow discharge is then initiated by applying bias to the cathode for the desired length of time. During the glow, the pressure rises to about 130 microns due to release of hydrogen from the ethylene.

The substrates used for the glow discharge apparatus are 3" x 3" squares of 10-mil stainless steel which is chrome-plated and polished on one side. The substrates are washed in alcohol and dried and then placed in a vacuum evaporator where they are coated with sodium chloride as a release agent. They are then immediately transferred to the cathode of the glow discharge apparatus and coated with carbon using glow times ranging from 15-80 seconds, and voltages of 2 to 2.8 kV.

For the first foils made, we attempted to mount them by the usual floating on water and subsequent pickup method. We found quickly that these foils are quite fragile and the success rate in mounting them was very poor. Consequently, we adopted the collodion coating process as used at Chalk River to provide support for the carbon foils during mounting and drying. No attempt was made to remove the collodion prior to irradiation testing although this can be done easily using a heat lamp or flash gun. In addition to foils mounted on conventional holders, several were mounted on aluminum rings and slackened using the technique reported by the Daresbury group. Slide 2 shows the die used and foils before and after the reduction process.

Irradiation testing of ORNL foils was done in August using, again, 10 MeV chlorine ions. Foils from nine separate glow discharges, as well as conventional vapor deposited foils were used in these tests. The main criteria for the foils was that they be as thin as practical, namely less than 10 $\mu g/cm^2$, since this is the thickness range of interest for stripper foil applications. The choice of 10 MeV chlorine ions as projectiles is a reasonable compromise between the need for high damage rates and hence reasonable irradiation times and the desire for particle energies which are representative of those which will be experienced by the first stripper foils in the new accelerator. Irradiations were carried out in a high vacuum chamber at pressures in the range of 5×10^{-8} torr, using a cryopump and liquid nitrogen cooled trapping to reduce the deposition of contaminants on the foils due to thermal cracking of residual hydrocarbons. The beam focus was adjusted to illuminate an area of about 2-3 mm^2 using a quartz phosphor immediately

in front of the foil position. The beam current was monitored by an electron suppressed Faraday cup, and the relative foil thicknesses were determined by detecting recoiling carbon atoms with a surface barrier detector mounted at an angle of 50° to the beam line.

The criterion used to define foil failure in these experiments was that the foil suffer a mechanical failure, that is, that a hole be formed somewhere on the foil. The time of failure was determined by visual inspection of the foil atfrequent intervals, although with the thicker glow discharge foil, which ran for 8-10 hours, there was a strong tendency to reduce the number of trips between the control room and the foil irradiation chamber, particularly between 2AM and 8AM!

The results of our measurements are summarized in Slide 3. It is apparent that there is a strong thickness dependence present for the glow discharge foils which is not evident or is much suppressed for the vapor deposited foils. Part of this effect could be thermally induced since the beam energy loss causes the thicker foils to be operated at a higher temperature. The calculated temperatures ranged from 300°C for the foils in the 2 $\mu g/cm^2$ region to 600°C for the 10 $\mu g/cm^2$ foil, and indeed the latter foil was found to be faintly luminous at the center of the beam spot. Another factor which may enter into the thickness dependence is the thinning which takes place in the latter stages of the irradiation. Slide 4 shows the variation in foil thickness observed by scanning the beam vertically across the foil. The open circles show the initial thickness measurement and it is clear that significant changes are occurring. In particular, foil 17 was scanned at two different fluences. The first scan was taken at relatively low fluence and shows a significant increase in thickness in the

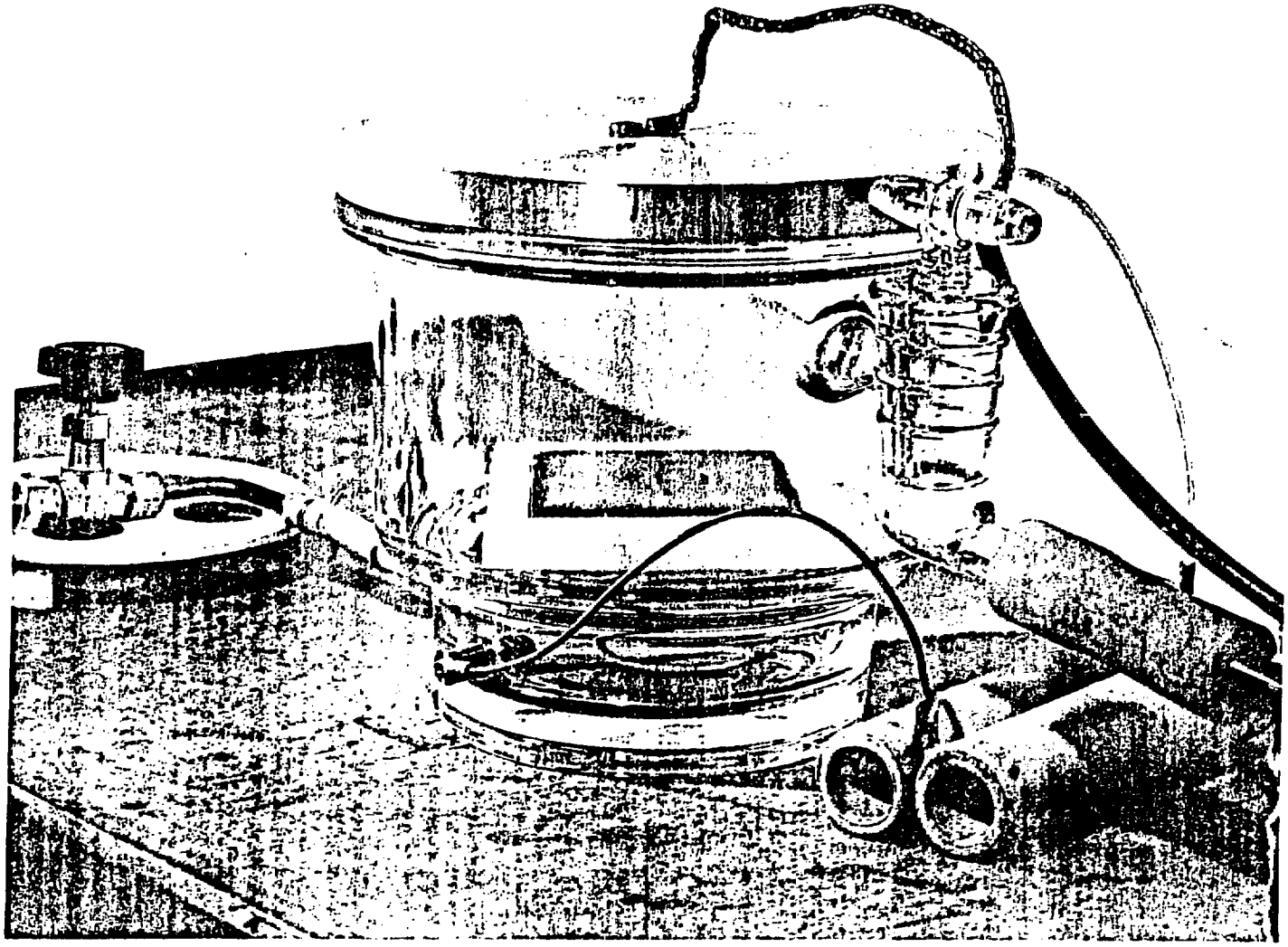
irradiated zone. A subsequent scan at high fluence shows the thinning which subsequently occurred and the thickness is in fact less than its initial value by some 9%. The thinning may weaken the foil to the point where it fails at the center of the beam spot. Such a failure is shown on Slide 5. It was also found that several foils, all having relatively short lifetimes, failed by tearing in the peripheral region and such a foil is shown in Slide 6.

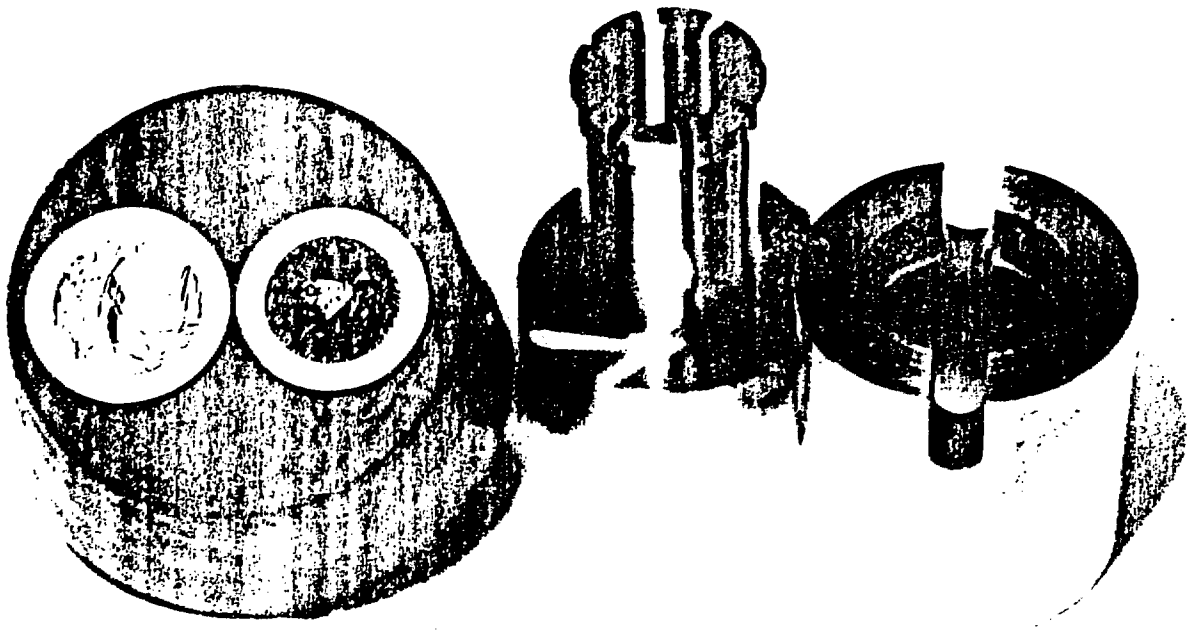
Subsequent to the testing, after the relative foil thicknesses were determined, we tried to correlate the thicknesses with the parameters used in the glow discharge. Our initial attempt at correlating these data is shown on Slide 7 which shows the thickness plotted as a function of the charge collected in the glow process, and there appears to be little correlation with behavior which would be expected if the collected charge corresponded to the collection of singly-charged carbon ions. In our second attempt, we considered only the time during which the glow was maintained and the result is shown on Slide 8. Except for some discrepancies at the low end, there seems to be a reasonable correlation between the foil thickness and the glow time. We are planning to study this correlation using well controlled pressure, time, and voltage parameters.

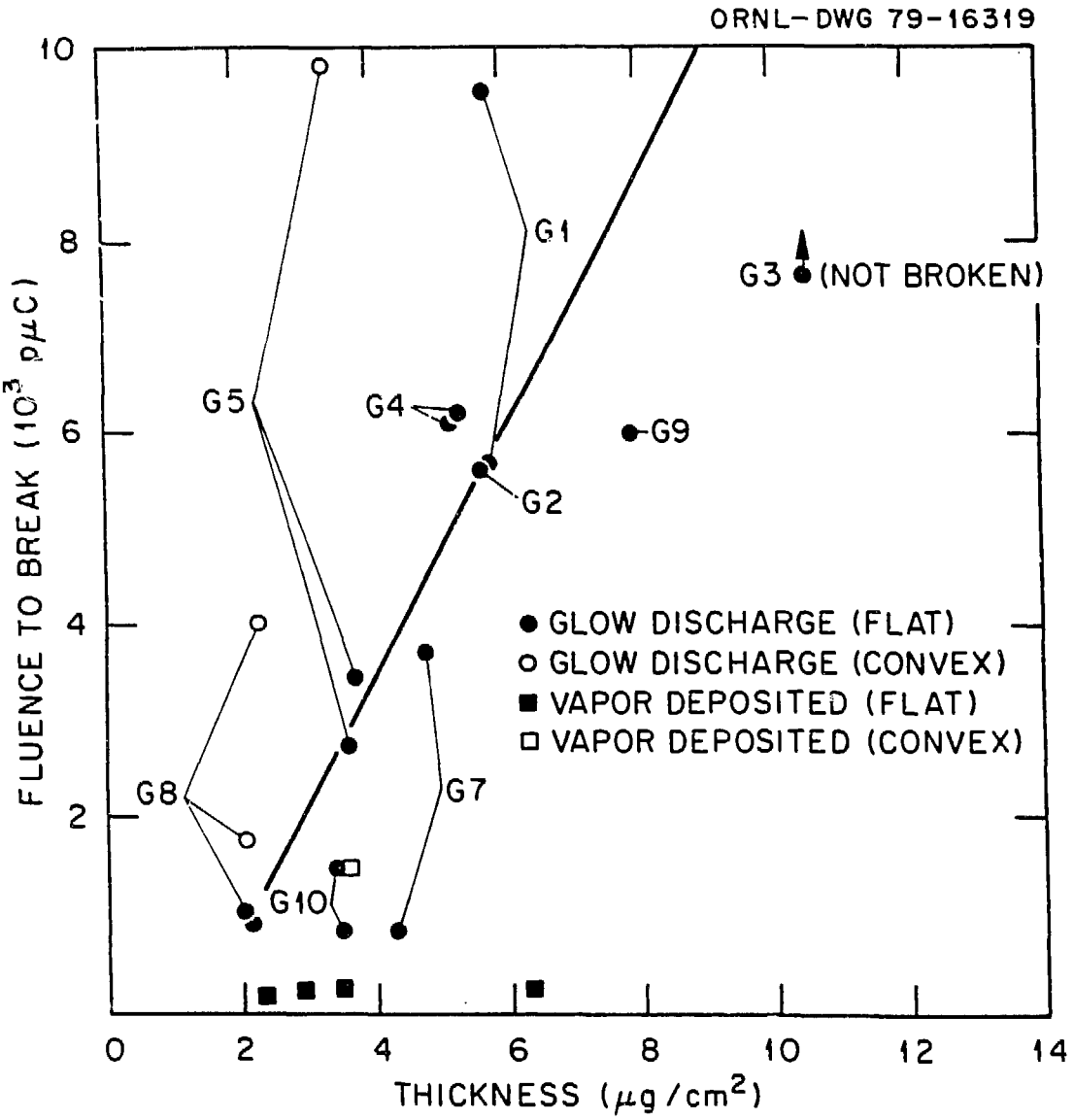
Recently, we discovered that slack foils could be made using a procedure which eliminates the ring reduction process and the problems involved in mounting the rings in the foil changer. In this procedure, the substrate itself is deformed as shown in Slide 9. By using the collodion backing it was found that foils deposited on such a substrate were sufficiently strong that they could be floated off and

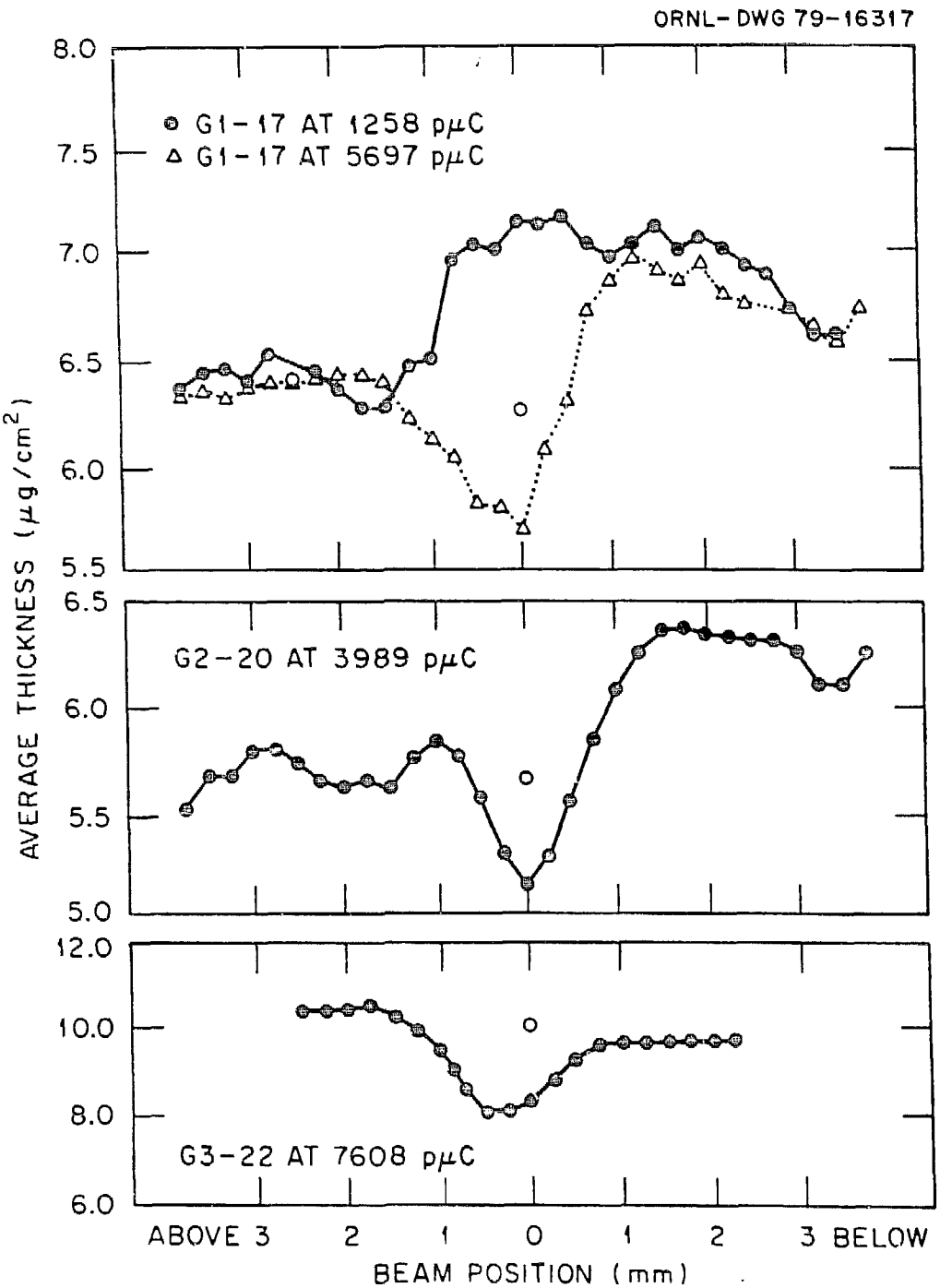
picked up without destroying their slackened character. Preliminary tests indicate that these foils perform comparably to those made using the ring reduction method.

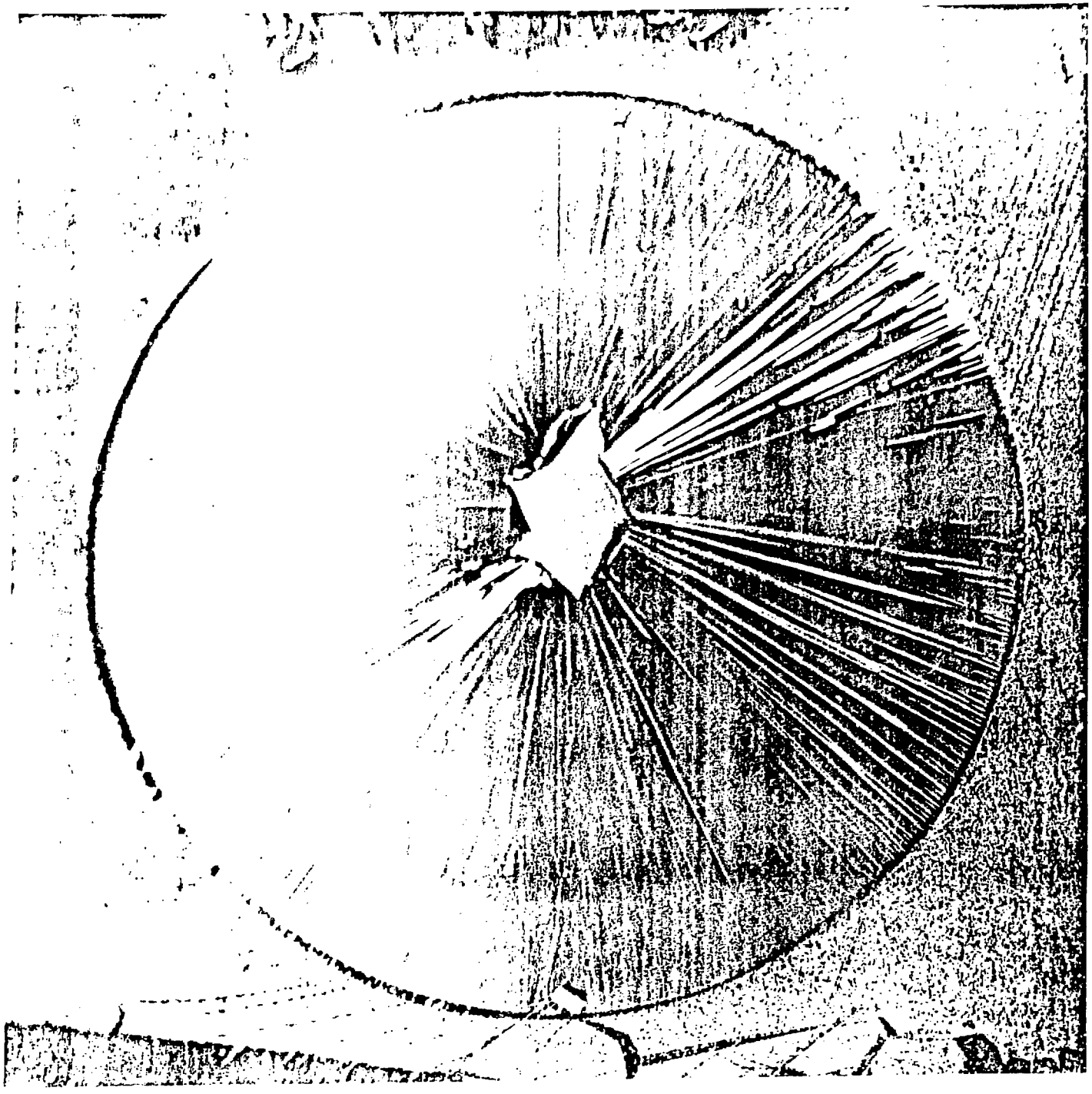
While the detailed differences in the structure of the foils made by vapor deposition and by the glow discharge technique are not understood at present, it is clear that these new foils represent a timely and valuable contribution to the field of heavy ion electrostatic accelerators.

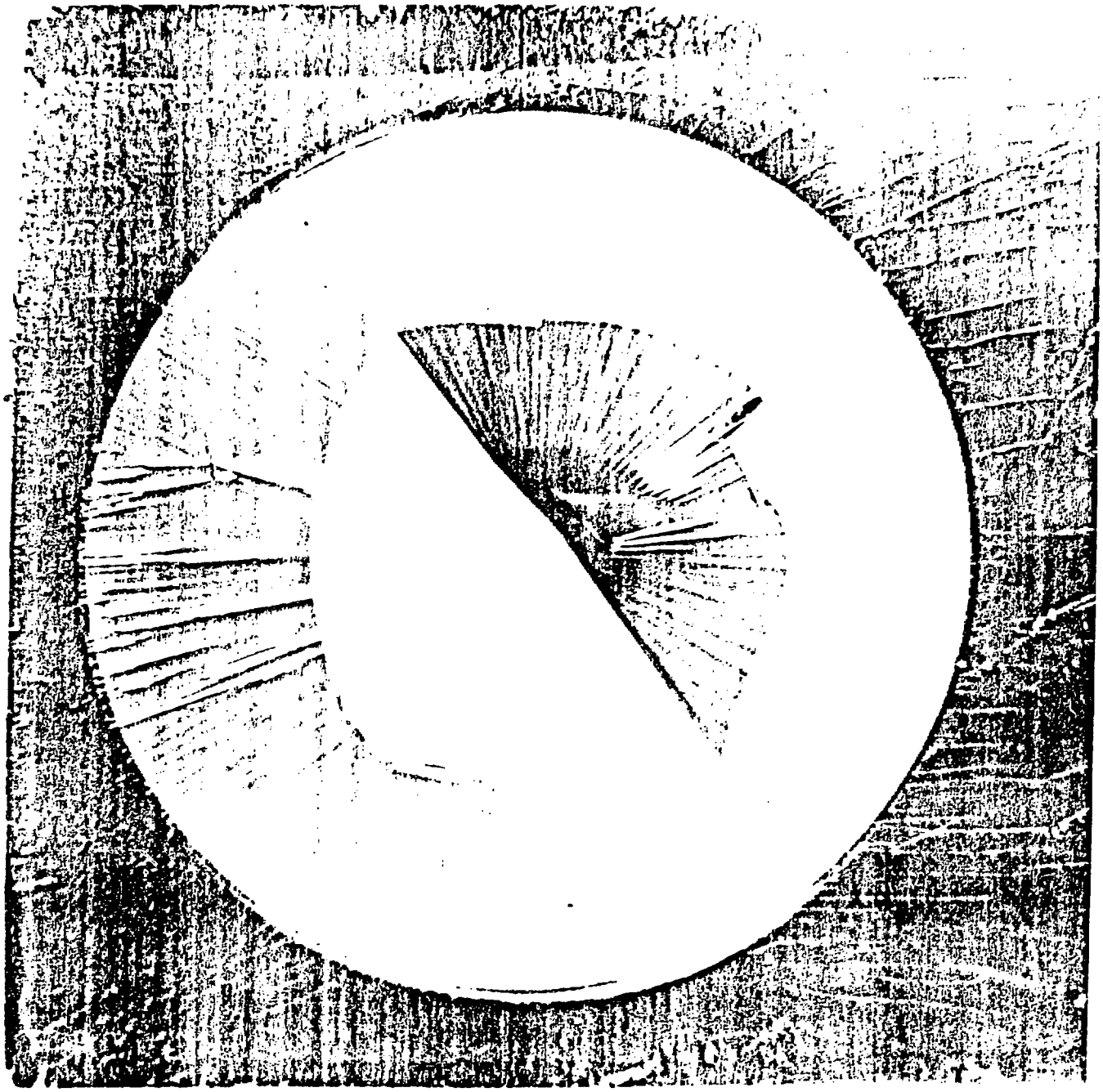


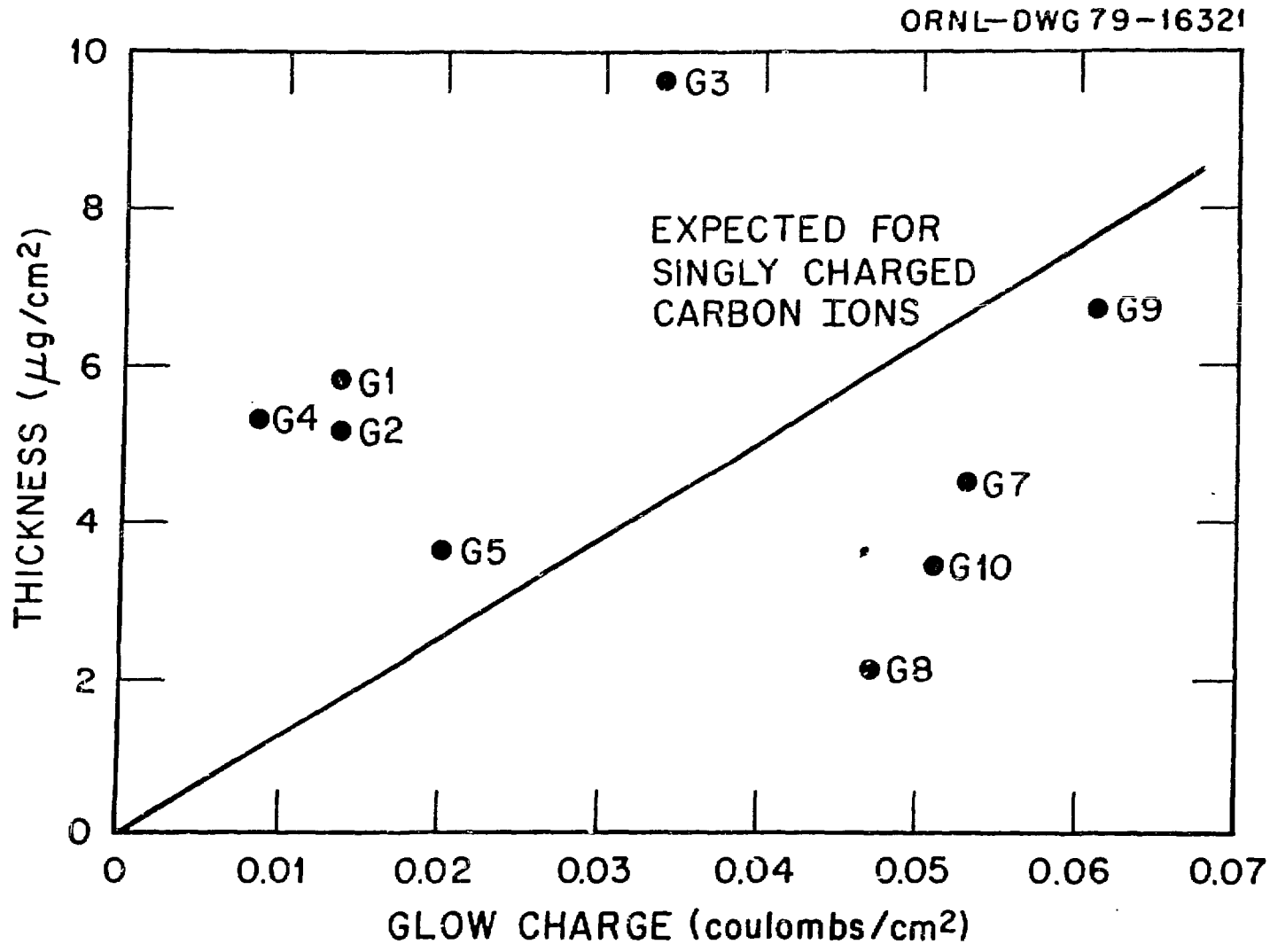


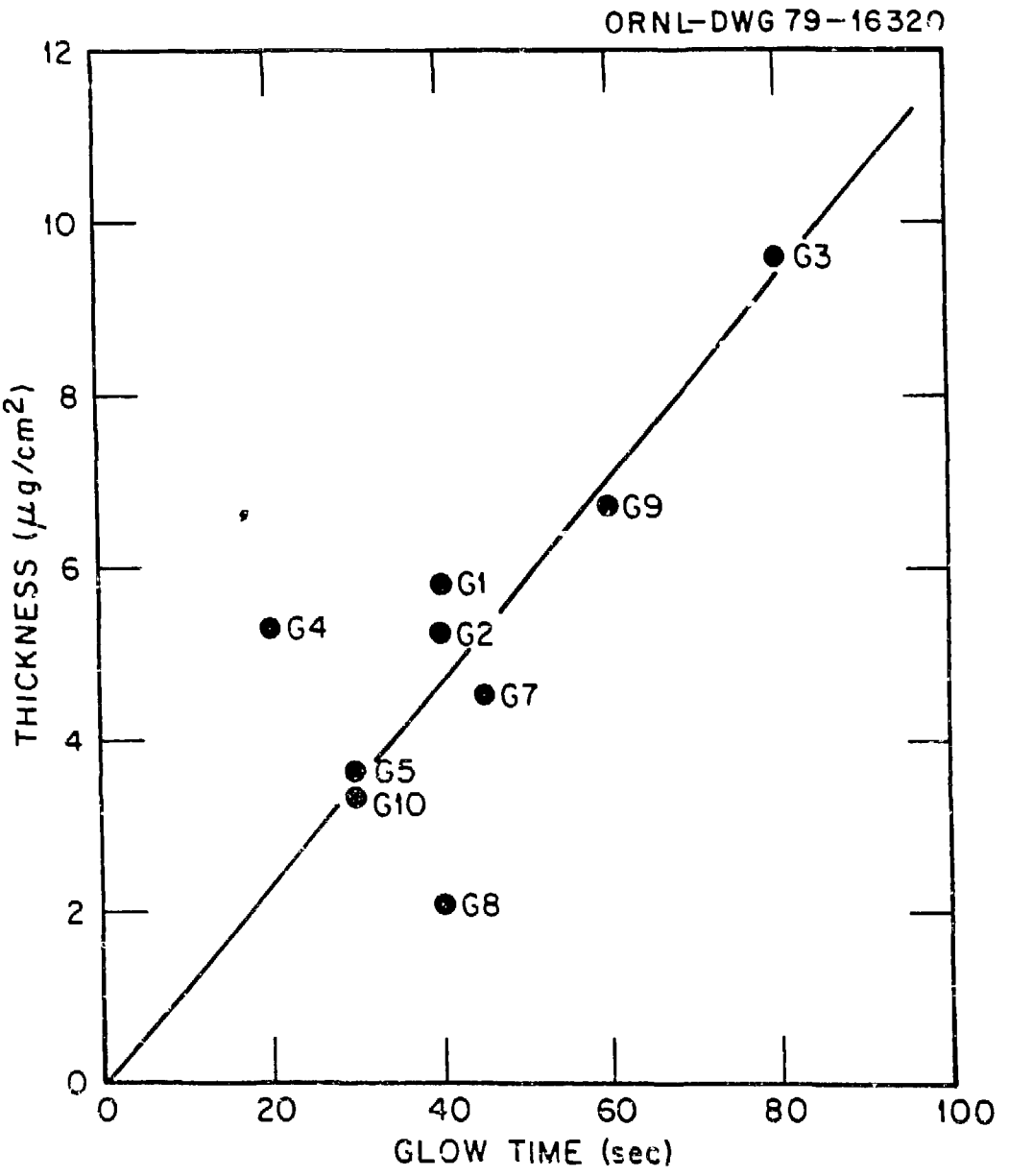

ORNL-DWG 79-16319
FLUENCE TO BREAK (10^3 pμC)
THICKNESS (μg/cm²)
G1
G2
G3 (NOT BROKEN)
G4
G5
G7
G8
G9
G10
GLOW DISCHARGE (FLAT)
GLOW DISCHARGE (CONVEX)
VAPOR DEPOSITED (FLAT)
VAPOR DEPOSITED (CONVEX)


ORNL-DWG 79-16317
G1-17 AT 1258 pμC
G1-17 AT 5697 pμC
G2-20 AT 3989 pμC
G3-22 AT 7608 pμC
AVERAGE THICKNESS (μg/cm²)
BEAM POSITION (mm)
ABOVE 3
2
1
0
1
2
3 BELOW
8.0
7.5
7.0
6.5
6.0
5.5
6.5
6.0
5.5
5.0
12.0
10.0
8.0
6.0






ORNL-DWG 79-16321
THICKNESS (μg/cm²)
GLOW CHARGE (coulombs/cm²)
EXPECTED FOR
SINGLY CHARGED
CARBON IONS
G1
G2
G3
G4
G5
G7
G8
G9
G10
0
2
4
6
8
10
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07


ORNL-DWG 79-16320
THICKNESS (μg/cm²)
GLOW TIME (sec)
0
2
4
6
8
10
12
0
20
40
60
80
100
G1
G2
G3
G4
G5
G7
G8
G9
G10